Novel optical amplification structures for future Dark Matter searches

- YAM 2026 -

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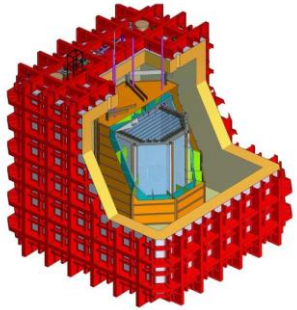
Dark Matter direct detection

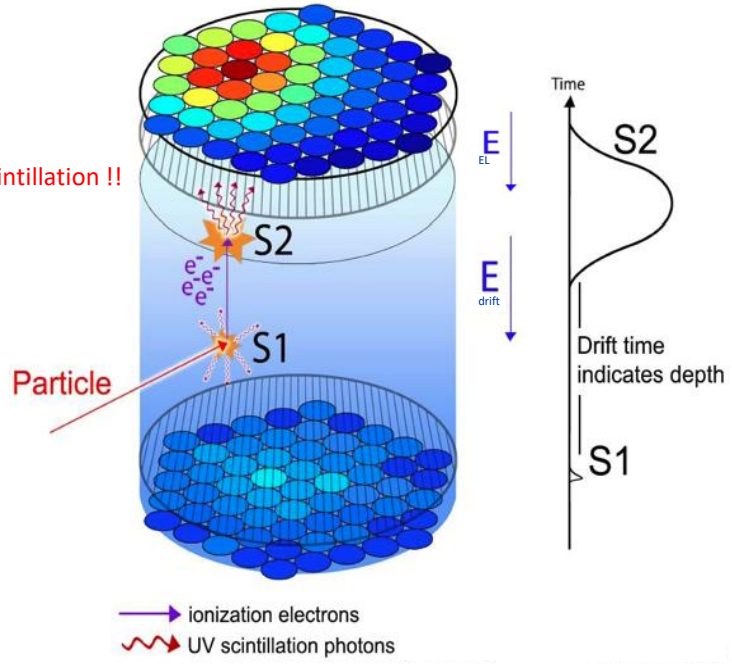
- **Weakly Interactive Massive Particles (WIMPs):**
  - **Expected**: elastic scattering with nuclei
  - **Signature:** nuclear recoil (few keV)
- **Extremely low event rate:**
  - **Low background** experiments → underground + Uar
  - **Ton-scale** detectors
- **Time Projection Chambers (TPCs):**
  - **Noble elements** (Ar, Xe) as interaction medium (target).
  - **Dual-phase** detectors lead the next generation of direct DM searches.



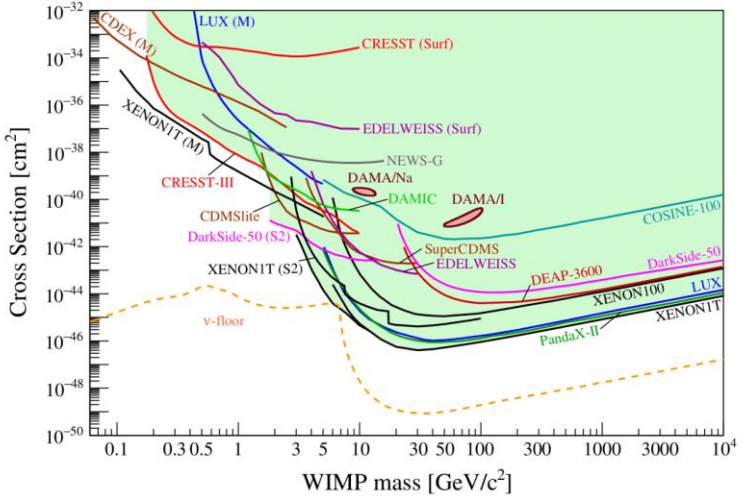
Darkside-20k

LNGS - L'Aquila, Italy

**VUV scintillation !!



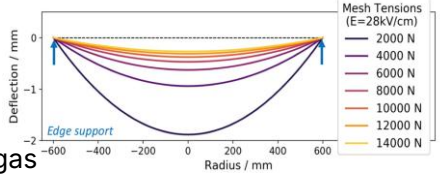
Dark Matter detection challenges



Build bigger detectors!!

(Improve light collection efficiency, bkg understanding and rejection, …)

Wires and meshes provide **great energy resolution**
BUT difficulties to scale up:



- Loss of tension with time
- Lack of modularity
- No option of direct coupling with solid WLS
- Difficulties at extracting e- from the liquid-gas interface

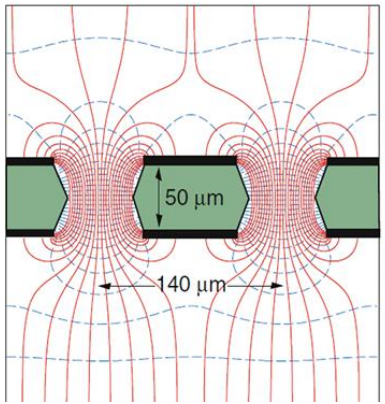
Field Assisted Transparent Gas Electroluminescence Multiplier
(FAT-GEMs)

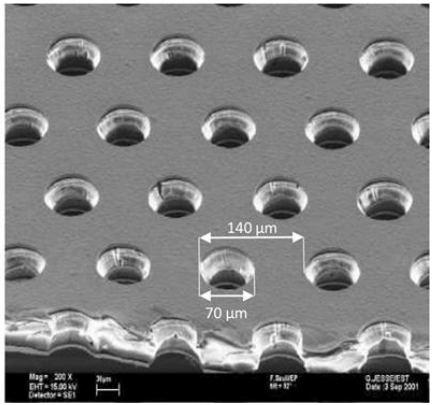
- **MPGD-based** structure
- Integration with **WLS coatings** (128 nm to 420 nm)
- Modular, **tileable**, and **radiopure**
- Robust mechanical design

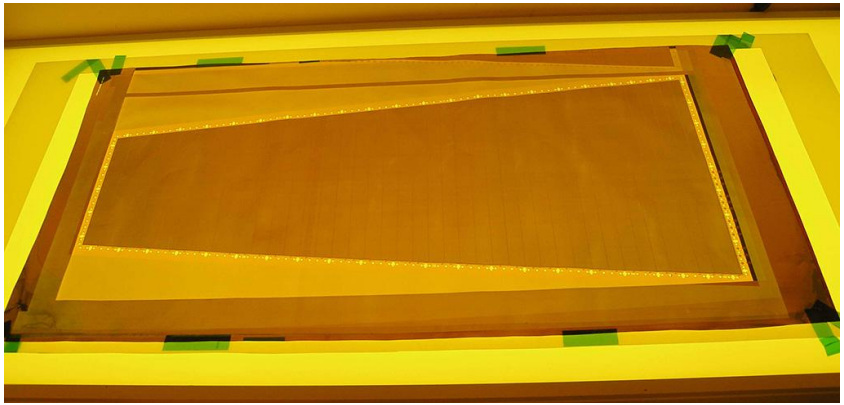
But what's a GEM?

A **Gas Electron Multiplier (GEM)** type of MPGD originally developed at CERN in the 1990s, consisting of a thin **insulating foil perforated with a dense hole pattern** and clad on both sides with a metallic conductor. https://doi.org/10.1016/S0168-9002(96)01172-2

- **High voltage** across the foil → **intense electric fields** inside the holes
- **Ionization electrons** drifting through the detector are collected in and **multiplied via avalanche**
- **Amplified charge** is collected on a readout plane
- Widely used across particle physics, medical imaging, and nuclear instrumentation







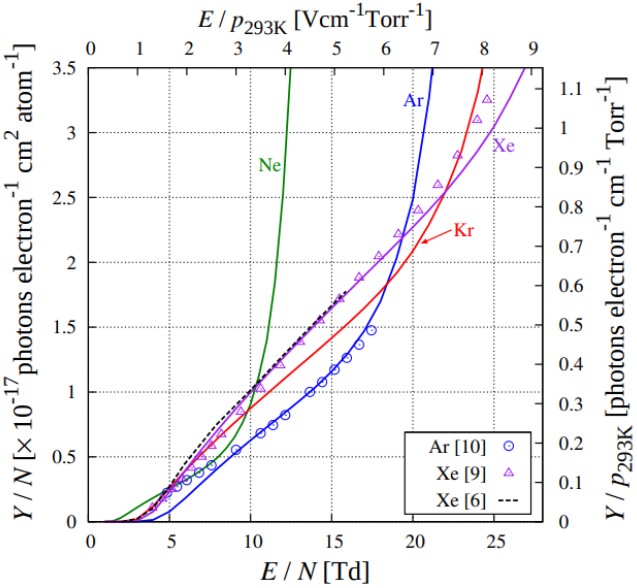
Electroluminescence

Dual-phase detectors are a preferred choice in **Dark Matter searches** (XENON, LZ, DarkSide)**.** Detection rely on **electroluminescence** mechanism in the gas phase where **large area wire planes or meshes** have been employed so far:

Electroluminescence:

- No charge multiplication – less fluctuations in signal.
- No ion feedback.
- Linear response with reduced electrical field.

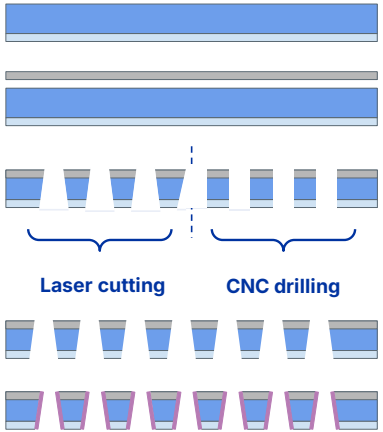
** Ar VUV scintillation not compatible with commercial photosensors

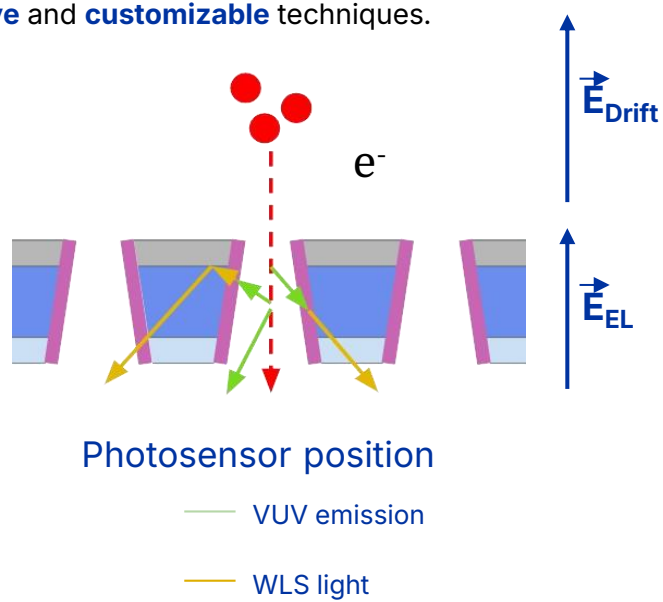


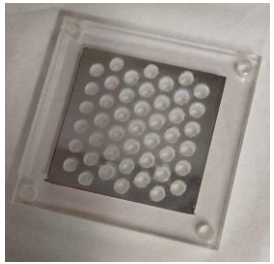
(C. A. B. Oliveira et al., Phys. Lett. B, 703 (2011) 217-222.)

Developing novel optical amplification structures

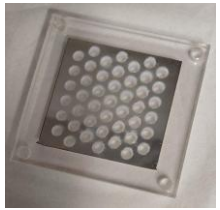
AstroCeNT is leading the production, being completely autonomous and developing a manufacture procedure based on **clean, low radioactive** and **customizable** techniques.



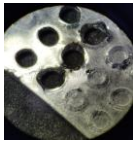


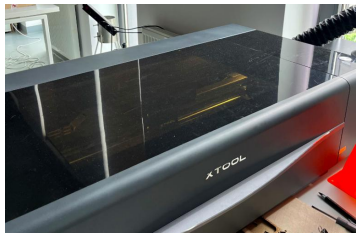


Production @AstroCeNT



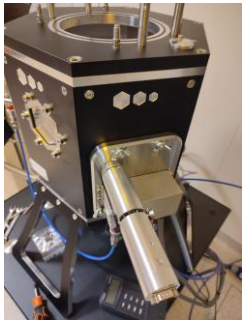
Laser cutting

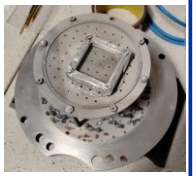


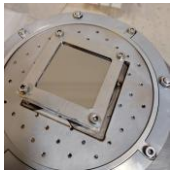


arXiv:2602.03273

Aluminum deposition

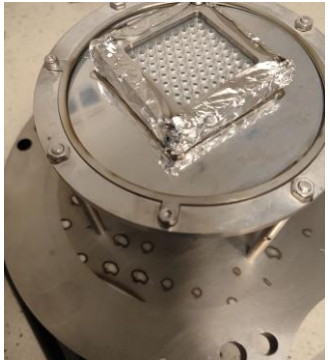






Annealing

WLS deposition



Testing


GSI
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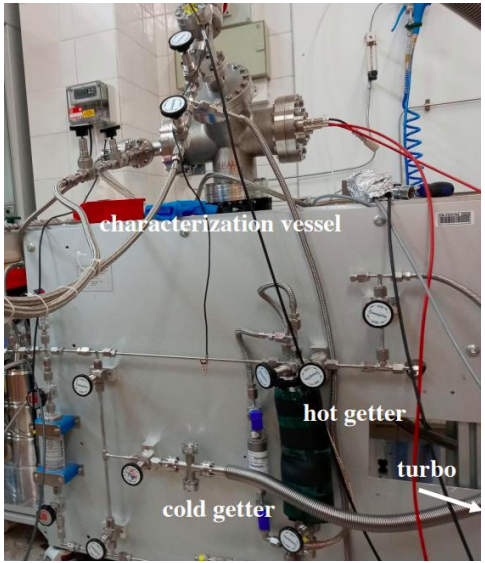
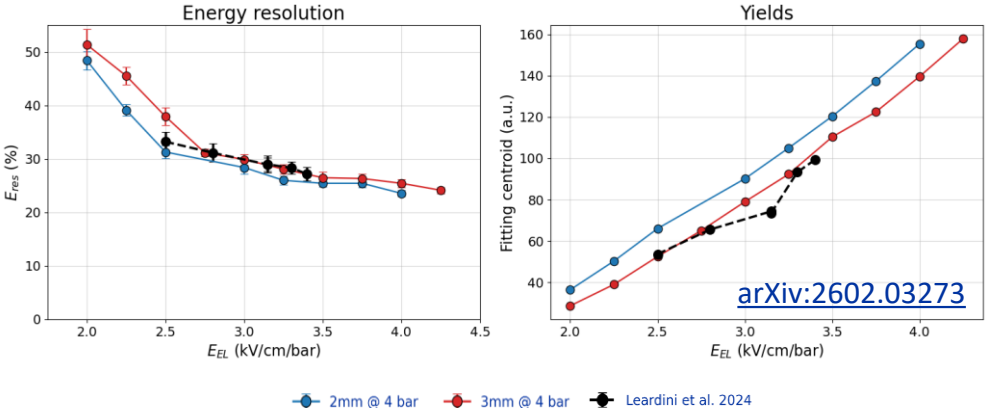
Istituto Nazionale di Fisica Nucleare
Sezione di Padova

Characterization in GAr at room temperature

Room temperature characterization was performed in gas **Ar** at **4 bar and 293 K → equivalent density to cryogenic operation** (1 bar, 87.5 K)



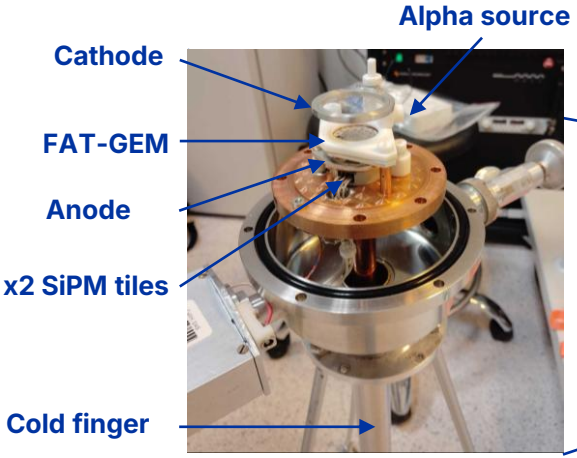


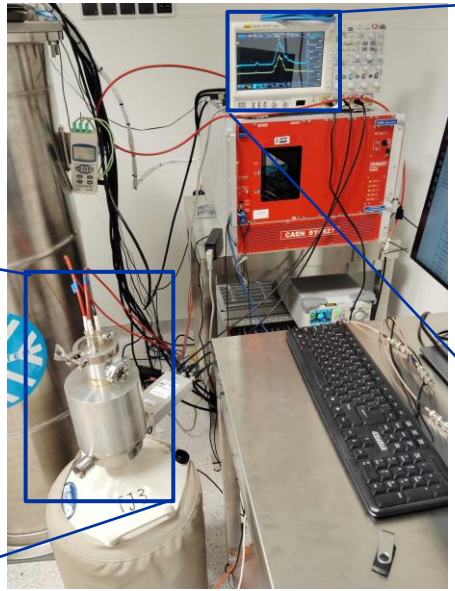
Main conclusions:

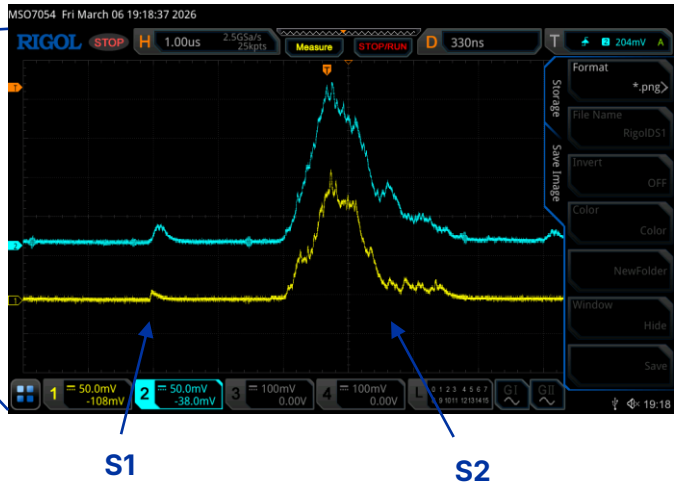
- Extended range of pressure-reduced electrical field.
- 20% improvement in light yield respect to previous productions.
- TPB wasn't deteriorated after electrical discharges through the holes.

Characterization in GAr at cryo temperature

ArGSet: Setup dedicated to study gas properties at cryogenic temperatures.



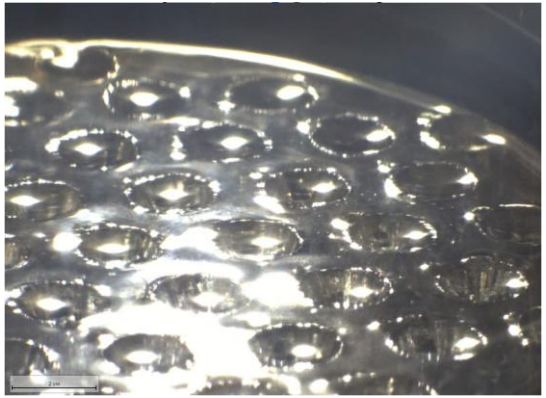




Signal in coincidence from the two SiPMs placed in the readout plane.

Ongoing Work

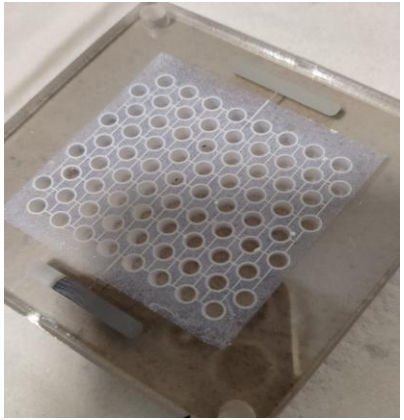
- **Floatability** tests:



- **Simulations**:
  - Optimize optical response (WLSE and light collection)
  - Understand effects of hole size variations and shapes in detector response.

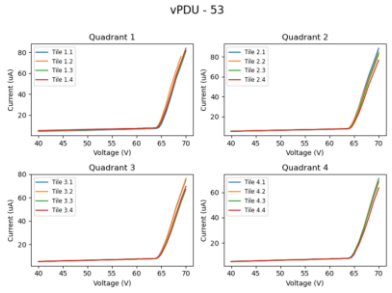
- Batch of structures produced at **CERN Workshop** are ready to be tested:
  - **Semi-transparent electrode** allowing for S1 detection
  - Photolithography

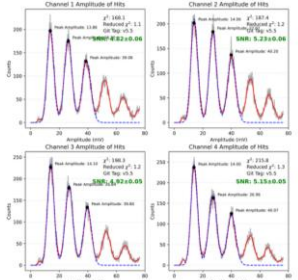
- Testing of **new materials:**



Other projects: DarkSide-20k vPDU testing

- veto Photon Detection Unit (**vPDU**) QA:
  - **16 SiPM** tiles modules (4Q x 4T)
  - Warm and cryogenic characterization:
    - Noise spectra
    - V breakdown
    - SNR
- **May 2025 – March 2026**





Summary

- Next generation DM experiments need for **bigger detectors**.
  - Current wire and mesh structures face **scalability, mechanical, and integration limitations**, motivating alternative solutions.
- Based on last results, **FAT-GEMs** are looking like a promising alternative.
- Future experimental campaign for **cryogenic characterization** is happening right now.
- **vPDU** testing almost completed with **~80 modules successfully tested** (after some reworks)

Are you interested?

- **Development of a Novel Electrostatic Focusing Readout for Large-Scale Hybrid Time Projection Chambers in Neutrinoless Double-Beta Decay Searches**
  Dr. Hab. Marcin Kuźniak & Dr. André Cortez
- **Exploring Spectral Dynamics of Argon Scintillation from Scintillation Threshold to Breakdown Voltage in MPGD Structures**
  Dr. Pedro Silva & Dr. Hab. Masayuki Wada
- **Development of cryogenic photosensors with digital readout systems for medical scanners and scientific experiments**
  Dr. Hab. Masayuki Wada

Talk by Pedro Silva tomorrow!

Thank you!

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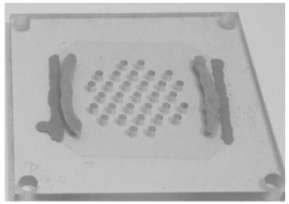
Backup slides

Brief FAT-GEM history

- HP Xe TPC
- Radiopure
- Translucid

(D. González-Díaz et al., J. Phys. Conf. Ser., 1498 (2020) 012019.)

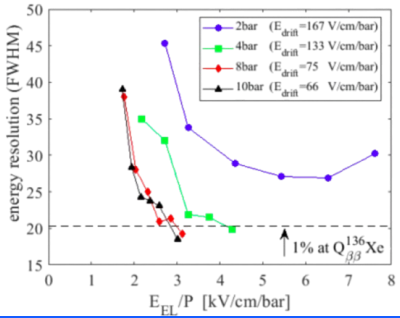


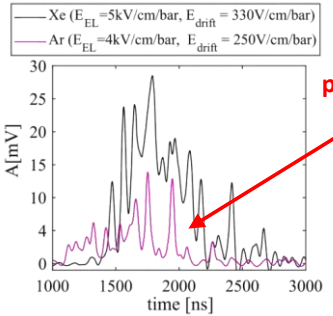
- Transparent bulk material
- PEN as WLS

(M. Kuźniak et al., Eur. Phys. J. C, 81 (2021) 609.)

(S. Leardini et al., Sci. Technol. 2 (2024) 1373235.)

2020 — **2021** — **2024** — **Present**





Ar blind photosensor!